THE DIAGNOSTICS SYSTEM FOR THE SPIRAL R.I.B. FACILITY

B. Launé
Institut de Physique Nucléaire
91406 Orsay Cedex, France
and
SPIRAL Group
GANIL
BP 5027
14021 Caen Cedex, France

ABSTRACT

The SPIRAL R.I.B. facility, based on a cyclotron, under construction at GANIL, will accelerate radioactive ion beams in a wide range of intensity (down to a few pps). The beam might also be mixed with other unwanted species. Tuning of the cyclotron and of the beam lines under these conditions presents difficulties that the diagnostics system should ease. The foreseen tuning process will be described as well as the hardware that has to be developed: nuclear physics techniques will be used but have to be adapted in order to become an efficient tool for accelerator and beam line tuning.

1. INTRODUCTION

The SPIRAL[1,2] project will accelerate various radioactive projectiles in a large range of energy (from about 2 up to 25 MeV/A) and intensity (from a few pps to 10^8 pps and up to 5.10^{11} for stable beams), by using the high intensity heavy ion beam available at GANIL to produce the radioactive nuclei by the ISOL method. The postaccelerator is a K265 cyclotron. Then both the beam lines and the cyclotron must be able to select the right species among a mixture of unwanted ones and to be correctly tuned for it. A first mass selection is operated in the VLE (Very Low Energy: ≤ 30 keV per charge) beam line: 5.10^{-3} for an emittance of 80π mm.mrad (possibly a few 10^{-4} if the LAMS spectrometer[3] is later built); the cyclotron itself will also give a few 10^{-4}, depending on the harmonic number and the number of turns.

The mixing of different ion beams is unavoidable in most cases, so that the use of an analog beam, unambiguously known and abundant, to pretune the beam lines and the cyclotron is foreseen. This pretuning will be made in parallell with the tuning of the primary beam, thus saving time. This analog beam must be selected carefully, taking into account the different requirements from the beam lines and the cyclotron. To shift to the radioactive beam, two methods are possible:

- keep $B\rho$ constant, then change the frequency and the voltages,
- keep the RF frequency (hence the velocity) constant and change the magnetic field and the voltages.

However, depending on how far the two species are in terms of charge-to-mass ratio, one or the other way may be selected; if it is within the VLE line mass selection, the tuning of the latter may not be changed.

As far as diagnostics are concerned, it is highly desirable to be able to check that the selected ion is present and that it is correctly tuned.

The main goal will then be to give the operators the necessary tools to perform these tasks, in terms of diagnostics equipment and of software help, as it is very important to ensure an overall transmission as high as possible.

The planned diagnostics system will be described. It is a collaboration between the SPIRAL group (GANIL, Caen) and the Institut de Physique Nucléaire (Orsay); the Service des Prototypes (CNRS, Meudon-Bellevue) has the responsability of the mechanical design of the radial and extraction probes.

2. LOW ENERGY BEAM LINE

This beam line is composed of two parts[1,2]: in a first part, an analysis is performed (R=200) and the emittance parameters defined for the second part which matches the 6-dimensional phase space to the cyclotron injection.

As the mass selection will be moderate, the different beams are rather mixed and only classical diagnostics are foreseen in the beginning for current and profile measurements. However, it is extremely important for the downstream tuning that one be sure that i) the selected species comes out of the target, ii) the polluting beams are identified iii) their abundance ratio measured: that means that an identification station (Ge, plastic and Si detector) be used, like in the SIRa experiments,[4] but an important effort should be made to turn this station into an easy-to-use tool. This detector could also be used for beam monitoring by sweeping the beam on it.

3. CIME CYCLOTRON

3.1. Tuning Process

As for the beam line, the same two choices are possible. In order to see the consequences for the cyclotron tuning, a simulation has been performed taking $^{33}_{18}Ar^{8+}$ as an example with the following parameters:

- q/a=0.2425
- $F_{revolution}$=5.9788 MHz, harmonic=2,
- B_o=1.6 T, E/A= 17 MeV/A
- V_{rf}=95 kV, n_{turn}=300, $R_{extraction}$=1.5 m

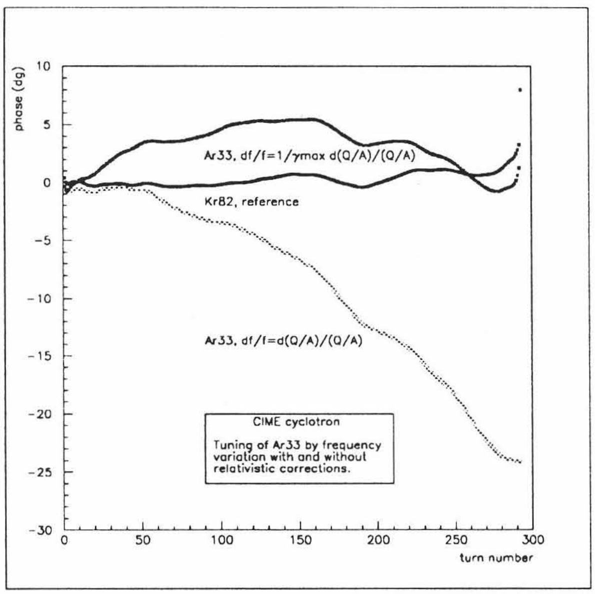

Figure 1. *Phase vs turn number after frequency variation*

By searching in the mass table, we select as analog $^{82}_{36}Kr^{20+}$ ($\Delta(q/m)/(q/m)$=6.8 10^{-3}, which, if the cyclotron is tuned for the radioactive beam could only be accelerated up to a radius of 0.3 m, taking 18 turns to reach a phase of 90°).

In order to calculate the variation for the shift from the analog to the radioactive beam, we write:

$$B\rho = \frac{mv}{q}$$
$$B\rho = \frac{m_0}{q} c\beta\gamma$$
$$\frac{\Delta B}{B} + \frac{\Delta\rho}{\rho} = -\frac{\Delta(q/m_0)}{(q/m_0)} + \frac{\Delta(\beta\gamma)}{(\beta\gamma)}$$
$$\frac{\Delta B}{B} + \frac{\Delta\rho}{\rho} = -\frac{\Delta(q/m_0)}{(q/m_0)} + \frac{\gamma^2\Delta\beta}{\beta}$$

In the case of magnetic field variation, we simply have:

$$\frac{\Delta B}{B} = -\frac{\Delta(q/m_0)}{(q/m_0)}$$

However, in the case of frequency variation the following **local** relation holds:

$$\frac{\Delta f}{f} = \frac{1}{\gamma^2}\frac{\Delta(q/m_0)}{(q/m_0)}$$

That means that a perfect phase history match is impossible, but by imposing $\int d\phi = 0$ we get:

$$\frac{\Delta f}{f} = \frac{1}{\gamma_{max}}\frac{\Delta(q/m_0)}{(q/m_0)}$$

It is confirmed by the simulation where the phase versus radius curves are shown on Fig. 1. The final choice of the method will be made after careful analysis of each specific case.

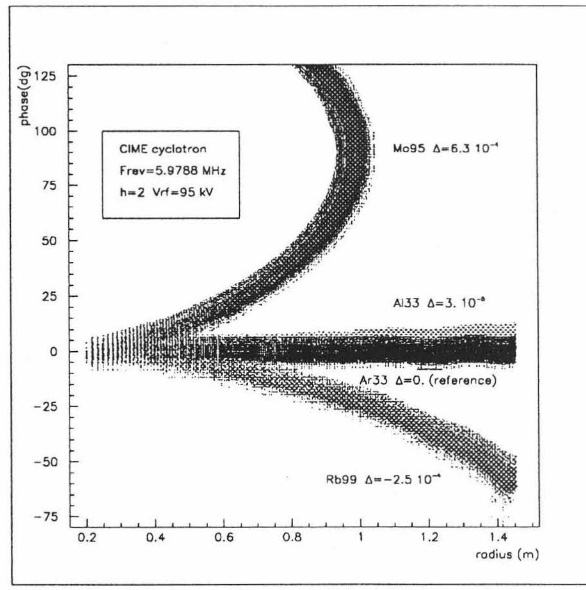

Figure 2. *RF phase vs radius for different* $\Delta = \delta(q/m)/(q/m)$

3.2. Beam Acceleration Simulation

As the injection beam line has a rather moderate selection in terms of charge-to-mass ratio, the cyclotron will accelerate a mixture of unwanted beams along with the selected species. In order to estimate the implications on the tuning, the following examples of beams (accelerated simultaneously) have been selected, by searching in the mass table (no attempt was made to be realistic, in terms of production in the target):

- $^{33}_{13}Al^{8+}$, $\Delta(q/m)/(q/m)$=-3.10^{-5}, n_{turn}=300, $d\phi = 6°$:

  an isobar which is accelerated in conditions extremely close to $^{33}_{18}Ar^{8+}$. The separation can only achieved by difference in energy loss through a target outside the cyclotron.

- $^{99}_{37}Rb^{24+}$; $\Delta(q/m)/(q/m)$=2.5 10^{-4}, n_{turn}=386, $d\phi$ =-69°:

it will be extracted (in 15 turns, hence with deteriorated properties).

- ${}^{95}_{42}Mo^{23+}$, $\Delta(q/m)/(q/m)$=-6.10^{-4}, n_{turn}=198, r_{max}=0.97 m: does not reach the extraction radius.

Phase vs radius curves are shown on Fig. 2. Various other diagrams were also produced to be able to better understand the probes output.

3.3. Diagnostics Hardware

Control of the acceleration in the CIME cyclotron requires detectors able to cover the following range: in terms of intensity from a few pps up to 5.10^{11} pps, in terms of energy: from about 0.5 MeV/A up to 25 MeV/A. As no equipment can handle such a range, it is necessary to use different kinds of detectors:

- 'classical' detectors, in any case mandatory, as beam tests, analog beam tuning, and possibly runs with stable beams are planned. The cyclotron will be equipped with (see Fig. 3):
  - a radial probe (from center up to extraction radius) with a differential and full beam current measurement, located between the two sections of the electrostatic deflector,
  - a set of central phase probes,
  - a retractable plate in front of each magnetic channel (CMS's).
- a 'low current' capability is necessary from the center up to the extraction radius. Candidates for the detectors are mainly: plastic scintillators followed by photomultiplier, semiconductors, ionisation chambers and microchannel plates. In addition to particle counting and energy measurements these detectors give also a time measurement, with respect to the cyclotron RF. Dephasing in the cyclotron acceleration, as shown by the simulations, is an important information for particle identification and of course for the correct isochronisation of the beam. The scintillator has been selected, because it is rather robust and cheap. In order to have an efficient photon collection, the photomultiplier will be installed as close as possible to the scintillator, that is on the probe itself, in the RF environment and in the strong magnetic field (such PM's do exist and are being tested). The radial probe will then carry a detector that can be retracted from the beam. As these detectors may be destroyed by accidentally receiving too much current, it will be possible to change them without breaking the machine vacuum. If the fact that two detectors on the same tool becomes difficult to handle, holes in each yoke are drilled to allow the installation of other(s) radial probe(s). It should be pointed out that these kind of detectors provides a new insight in the accelerated beam properties[5] and, by carefully reducing the intensity, may be used as normal beam diagnostics tools.
- an identification station in the cyclotron itself, before extraction, as the energy will be sufficient for a Si $E.\Delta E$ detector. A dedicated probe, with a reduced radius range, will be installed for this purpose.
- by using precautions, one should be able to detect with 'classical' diagnostics a few pA of beam current, (1 pA corresponds to 6.10^6 pps for a unit charge, then some exotic beams should be measurable with those 'classical' diagnostics); the polarity of the repelling ring of the Faraday cup can be inverted in order to amplify the beam current.[6]
- mass measurement experiments at GANIL with SSC2[5] have shown that Si detectors and scintillators can be put on a radial probe of a cyclotron and used successfully to tune it (mass measurements will also be possible with CIME by using the radial probe).
- beam current reduction equipment such as pepperpots should be implemented as well as fast beam supressor to protect the detectors.
- detector development will be made by setting up a full scale experiment in one of the present GANIL Separated Sector Cyclotrons:
  - to gain experience on this kind of detectors and the associated electronics (in a first step, only off-the-shelf modules and simple PC-based offline data analysis capabilities),
  - allow the definition of an electronics, integrated in the control system of the cyclotron to be able to use automatic tuning tasks.

4. MEDIUM ENERGY BEAMLINE

Classical diagnostics such as Faraday cups (adapted to be able to measure current as low as possible), secondary emission multiwire profile and phase width monitors, as already existing in the present GANIL beam lines, will be implemented. But detectors able to measure the beam current and profile at low intensity are also planned at selected locations. The accumulated experience from the LISE spectrometer[7] (ionisation chambers...) will be used in designing such detectors. The control that the wanted species is present after the extraction of CIME can be made using a Si $E.\Delta E$ telescope. In the case of beams that can only be separated by stripping or differential energy loss, it might be useful to have another telescope to check the separation downstream. Scintillators providing particle counting and time signal are foreseen, that could be used for beam monitoring and feedback loops.

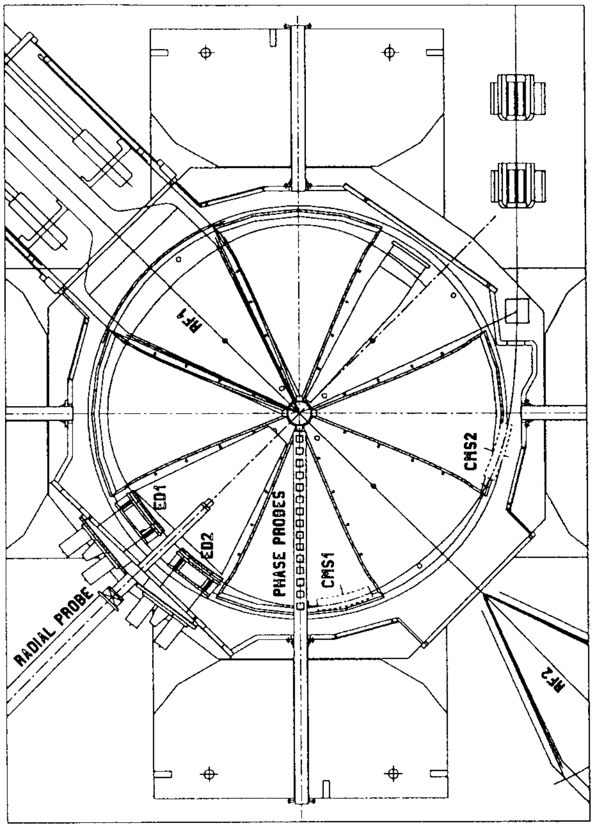

Fig. 3. *CIME Cyclotron median plane*

5. CONCLUSIONS

Developments will be made to gain experience on detectors that were mostly used in nuclear physics experiments and rarely in beam tuning. They will help select the better ones in terms of reliability, range (both intensity and energy) and flexibility. An effort will also be made to include these detectors into the control system of the machine, that has never been done before. Another effort will be applied in the beam simulations in order to get a very good understanding of the cyclotron and help design the probes. Detailed magnetic field maps should be obtained. The nuclear physicist community will soon select a limited number of typical beams in order to extensively study realistic cases and prepare the first radioactive beams that are expected in 1998.

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