CYCLOTRON TUNING AS A REBUNCHER

D. Bibet, M.H. Moscatello
GANIL, B.P. 5027, F-14021, Caen Cedex, France

Abstract

A new method is being developed at GANIL to reduce the length of the beam bunches. It consists in tuning a SSC as a rebuncher by increasing the magnetic field over the last accelerated turns. This method has been applied on the SSC2 to reduce the time length of the bunches delivered to the experimental room. Encouraging results has led us to apply the same method on the first SSC in order to reduce the phase extension of the beam injected in the second SSC and subsequently minimize energy spread of the ejected beam. Procedure is described and results presented.

Physicists' wishes

In most experiments the time at which the nuclear reaction occurs is an important information. Mainly for the time of flight measurements, which gives the velocity of the particles produced, the time resolution is crucial. Present detectors have a time resolution of 0.1 to 1.0 ns typically. The most convenient and efficient method to measure the time of flight is to determine the time of arrival in the detector with respect to the rf beam pulse. Therefore, the timespread of the beam pulse should be minimized, and should be ideally shorter that the time resolution of the detector.

1. PRINCIPLE

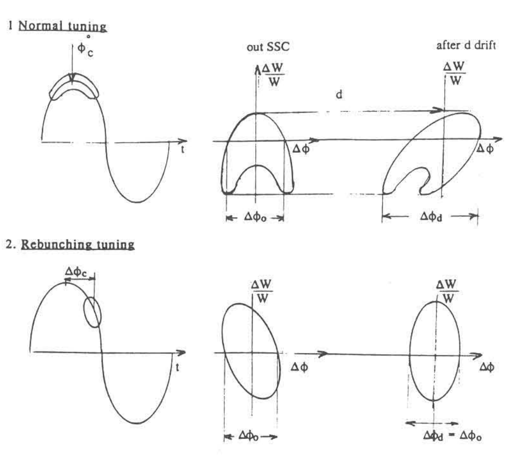


Figure 1

The phase ϕ_i of the particle i after d meters drift is :

$$\phi_i = \phi_{oi} + \frac{180}{2\pi\,\bar{r}} \times \frac{h}{\gamma^2} \times \frac{\Delta W_i}{W_o} \times d$$

and the central beam shift is :

$$\Delta\Phi_C = -2\pi \cdot \frac{h\ .\ N}{\gamma i\ .\ \gamma f} \cdot \frac{\Delta B}{B}$$

$\Delta\phi_o$: phase extension at the central momentum
$\Delta\phi_d$: total phase extension after d meters drift
$\Delta\Phi_C$: central beam phase shift for the last turn after a $\Delta B/B$ perturbation on the last N turns
h : rf harmonic
γi, γf : relativistic factor respective to radius ri, rf
$\Delta B/B$: magnetic perturbation applied between the ri and rf radius

from the reference 1 we know that

. the d length drift giving the minimal phase extension is

$$d = -\gamma 2\,\frac{\sigma 43}{\sigma 44} \qquad (1)$$

. and the l length pulse at the d distance is

$$l = \sqrt{\sigma 33 + (d\sigma 43/\gamma^2)} \qquad (2)$$

where σıj are the matrix elements of the beam matrix σ at the extraction of the cyclotron[1)]

2 SIMULATION [2)]

A simulation has been computed for the SSC2 using the computer code EJEC51[1)]

beam characteristics of the $^{132}Xe^{44+}$ are :

. extracted energy = 43.5 MeV/nucleon
. rf frequency = 9.38 MHz harmonic h = 2
. radial and transverse emittance = 5 π mm.mrad

. without perturbation

beam characteristics at the ejection point are :

pulse length l = 0.142 m
momentum spread $\Delta p/p = 0.846\ 10^{-3}$

. with a constant field gradient perturbation

of $+0.2\ 10^{-4}$ T/m extended on the 16 last centimeters of the acceleration path ; we get at the extraction point

pulse length l = 0.140 m
momentum spread $\Delta p/p = 1.1\ 10^{-3}$
central beam shift $\Delta\Phi_C = -37$ ° RF

the longitudinal waist point given by equations (1) and (2) :

is located at d = 108.9 m downsteam
and pulse length l = 0.088 m

effective gain for the physicist would be more if we consider the increasing phase drift it would have had without rebunching effect.

3. TUNING PROCEDURE

. firstly we do the standard tuning of the cyclotron and single turn extraction is verified with a time structure detector

. then field perturbation is applied using the last isochronism trim coils.
- the rf phase cavities must not be changed
- isochronous field pattern has to be corrected in front of the perturbation because of the return field effect of the trim coil change
- voltage acceleration is increased to compensate the lost of gain per turn due to the shift of the central phase on the last turns. It is adjusted to get the same extracted turn
- energy spread and time pulse length are measured at a given distance

. pulse length on the target is whether estimated or measured and magnitude perturbation can be adjusted

3.1 Limitation

. single turn extraction is a necessary condition
. field gradient has to be limited to respect of the matching conditions
. increasing of the energy spread induce by acceleration on the non-isochronous turns limit the turn separation extraction

3.2 Advantages and inconveniences

. tuning procedure is a little more complicated and the tuning time machine takes more time

. if the rf phase value is lost it is difficult to refine the optimum value because turn separation at extraction is not yet the best test

. increased energy spread

. bunch length reduction can be optimized for a dedicated room experiment

. bunch length reduction is achieved without or a very little lost beam intensity

. test experiments have shown a more stable beam time structure than the previous method using slits and less sensitive to any rf voltage or magnetic fluctuations.

4. RESULTS ON SSC2

Fig. 2 shows some results obtained on the SSC2 for the ^{132}Xe beam. The standard tuning gave 1.15 ns (half height) length time bunches after 40 m drift, then with +80 A applied on the last trimcoil we got bunches reduce to 0.215 ns on the target experimental room D3 located 100 m downstream SSC2.

For the ^{181}Ta beam it has been necessary to applied +120 A to get a factor 2 of reduction (see Fig.3).

Pictures 4 and 5 show a scanning of the longitudinal emittance of the ^{208}Pb beam. For the standard tuning we can see that bunches are well placed on the top of the sinusoid. With only a +90 A perturbation, bunches are not sufficiently shifted on the sinusoid as shown Fig. 5. We tried to apply a bigger perturbation (+150 A) but we got two turns extracted.

Fig. 6 gives the perturbation obtained on the axis of the four sectors magnet.

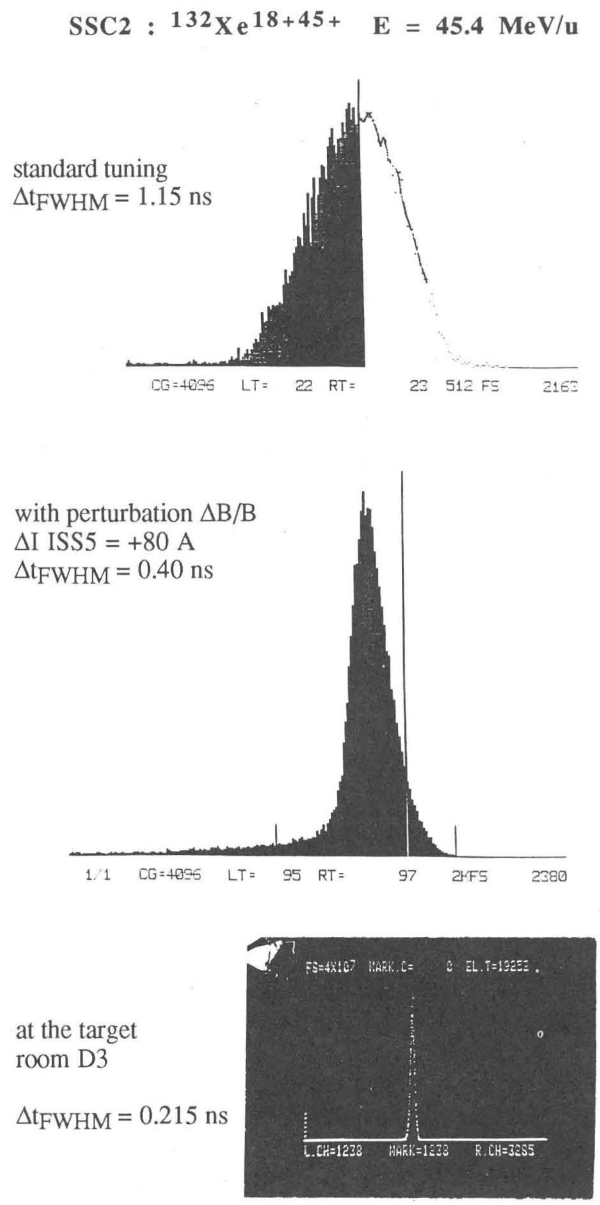
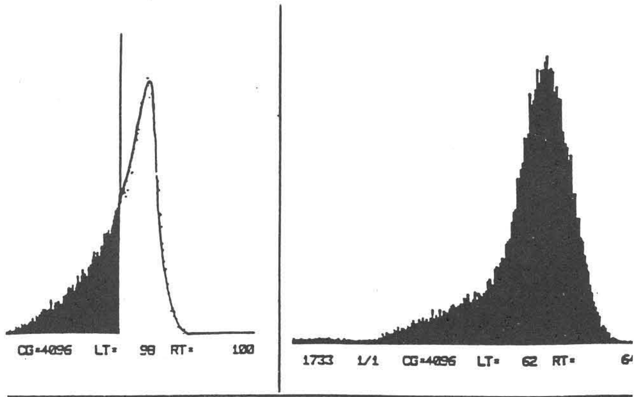


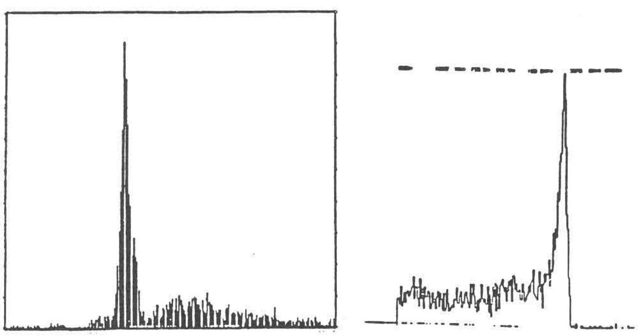
Figure 2

SSC2 : $^{181}Ta^{23/57+}$ E = 39.6 MeV/u



Initial tuning
$\Delta t_{FWHM} = 1n$

with perturbation
$\Delta t_{FWHM} = 0.55ns$



with perturbation target G2
$\Delta t_{FWHM} = 0.60$ ns

with perturbation target G4
$\Delta t_{FWHM} = 0.55$ ns

Figure 3

SSC2 : $^{208}Pb^{23/56+}$ E = 29MeV/u
Initial tuning

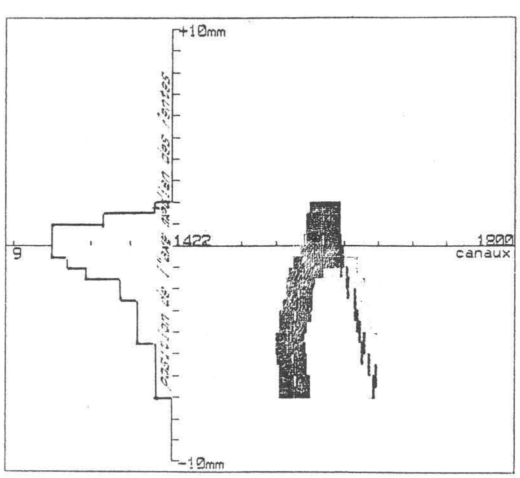


Figure 4

SSC2 : $^{208}Pb^{23/56+}$ E = 29MeV/u
with field perturbation ΔI ISS5 = +90 A

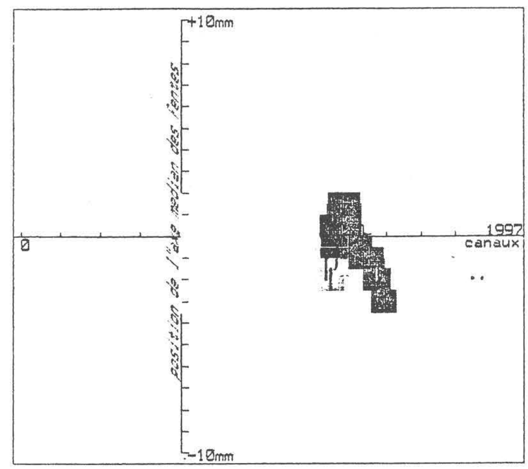


Figure 5

SSC2 : $^{208}Pb^{23/56+}$ E = 29 MeV/u
B f(Raxis)

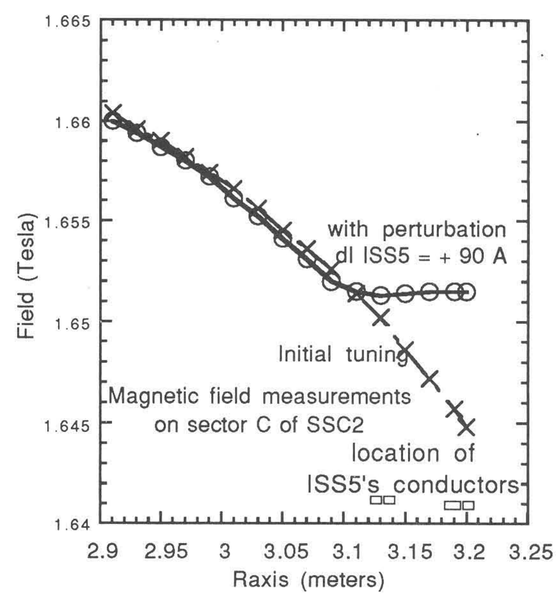


Figure 6

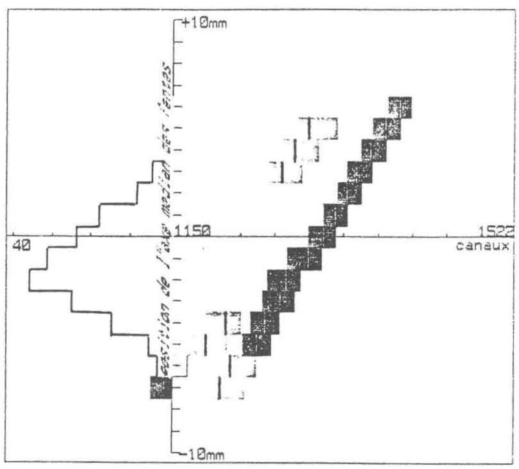
5. RESULTS OF SSC1

Encouraging results obtained on SSC2 led us to test this method on SSC1 in order to reduce the phase extension of the beam injected in SSC2.

If we got satisfying result with ^{36}Ar beam with a transparency of SSC2 near 100% ; it has been very different with ^{238}U beam. Between the two SSC, beam is passing through a stripper foil which produces a large energy spread and straggling giving a corresponding increase of the space phase volume. In this case objet point for the ($\Delta W/W$, $\Delta\phi$) phase space is still the stripper and the resulting effect of SSC1 perturbation turns out be very small. Nevertheless we have observed a small reduction of the longitudinal emittance given by a reduction of $\Delta\phi$ at the stripper. So we are still interested in another test with lighter ions, which stripper effect is smaller.

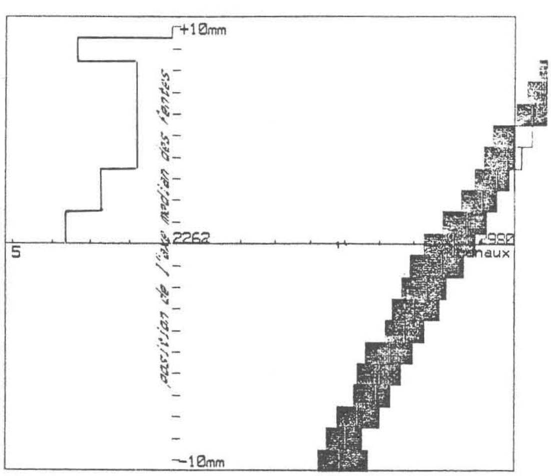
The following pictures show the different results for $^{238}U^{24/58+}$ E = 24 MeV/u obtained with non stripped and stripped beam.

SSC1 : initial tuning non stripped beam



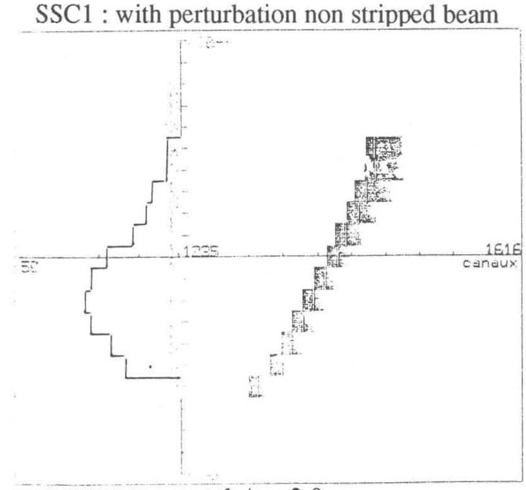
total Δt : 2.3 ns

SSC1 : initial tunning beam stripped



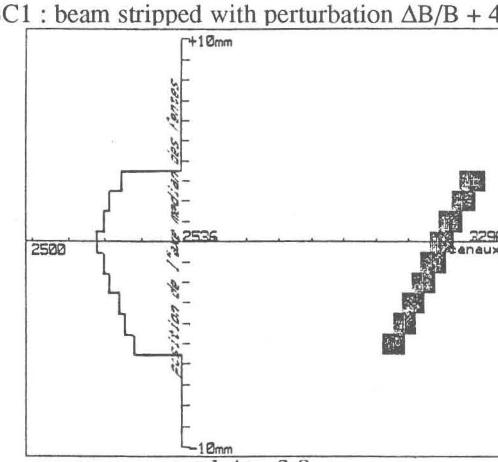
total Δt : 4.3 ns

SSC1 : with perturbation non stripped beam



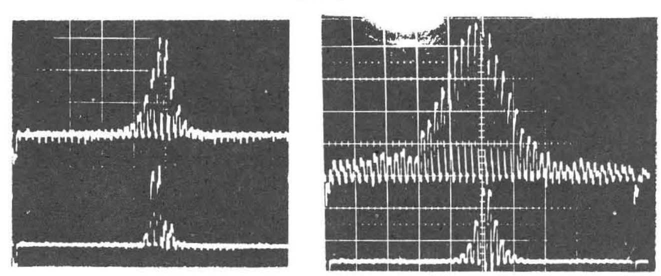
total Δt : 2.0 ns

SSC1 : beam stripped with perturbation $\Delta B/B$ + 45 A



total Δt : 3.8 ns

Energy spread



non stripped beam $\Delta W/W = \pm 0.5\ 10^{-3}$

stripped beam $\Delta W/W = \pm 1.6\ 10^{-3}$

REFERENCES

[1] J. Fermé, "Calcul au premier ordre des termes de couplage et de la matrice faisceau adaptée dans le cas général d'un cyclotron isochrone" report GANIL R89-03

[2] M.H. Moscatello, "Diminution de la longueur en phase des pulses par réglage d'un cyclotron en regroupeur" report GANIL 561.91/ml