DYNAMICS OF ^{197}AU^{+78} IONS GENERATED IN RECOMBINATION WITH COOLING ELECTRONS IN THE NICA COLLIDER

A.V. Eliseev, O.S. Kozlov, A.B.Kuztnetsov, I.N. Meshkov, A.O. Sidorin, A.V. Tuzikov, A.V. Philippov, JINR/VBLHEP, Dubna, Russia

Abstract

In the NICA Collider [1], recombination of original $^{197}Au^{+79}$ ions with cooling electrons in the electron cooler will lead to generation of $^{197}Au^{+78}$ ions. Dynamics of these ions in the energy range 1 – 4.5 GeV/u when the ion beam is bunched with RF voltage (collision mode operation) is considered in this report. It is shown that some part of 78+ ions can be involved into synchrotron motion when other part suffers a chaotic motion regime. Most of these ions circulate in vacuum chamber until further recombination into the charge state of $^{197}Au^{+77}$ and then leave the Collider acceptance very fast. The evolution in time of the ion distribution over the Collider aperture is presented

INTRODUCTION

Longitudinal motion of a multi-component ion beam can be in synchronism with an accelerating field when the revolution period T does not depend on the charge and mass of the ion in any moment of time. In differential form this condition is:

$$\frac{\Delta T}{T} = \frac{\Delta R}{R_0} - \frac{\Delta\beta}{\beta} = 0 \qquad (1)$$

Variation of the average radius R can be expressed as follows:

$$\frac{\Delta R}{R_0} = \alpha\left[\gamma_0^2\frac{\Delta\beta}{\beta_0} - \frac{\Delta\left(Z/W_r\right)}{Z_0/W_{r0}}\right] \quad , \qquad (2)$$

The relative velocity and momentum deviations of the beam components are:

$$\frac{\Delta\beta}{\beta_0} = -\frac{\alpha}{1-\alpha\gamma^2}\frac{\Delta\left(Z/W_r\right)}{Z_0/W_{r0}}, \quad \frac{\Delta p}{p_0} = \frac{\alpha\gamma^2}{1-\alpha\gamma^2}\frac{\Delta\left(Z/W_r\right)}{Z_0/W_{r0}} \quad (3, 4)$$

Where α is the ring compaction factor, β, γ – relativistic parameters, Z – particle charge, W_r – rest energy, index zero corresponds to the main component of the beam.

All the particles can be accelerated if aperture allows. As for collider operating at constant energy the particles not involved in synchrotron regime circulate in vacuum chamber as well.

In electron cooler of the NICA Collider the ions of Au^{+79} after successive recombination with electrons will transfer into Au^{+78}, Au^{+77} and so on. The ions in different charge states, involved into synchrotron motion will arrive to the detector sites simultaneously. This may contort physical experiments and hamper the feedback steering of the main beam. The ions forming coasting beam will create an unwanted noise.

PHASE SPACE MOTION OF IONS WITH DIFFERENT CHARGE STATE

RF Bucket Parameters

The bunch length in the NICA collider is chosen to be 0.6 m (rms) independently on the energy. The relative momentum spread (σ_p) is linearly proportional to relativistic gamma and varies from $6\cdot10^{-4}$ at 1 GeV/u to $1.7\cdot10^{-3}$ at 4.5 GeV/u [2]. The bucket height keeps ~3.7 σ_p regardless energy. Shift of the synchronous energy between Au^{+79}, and Au^{+78} (centres of corresponding buckets) and the bucket height are represented in the Fig.1 as functions of the particle energy.

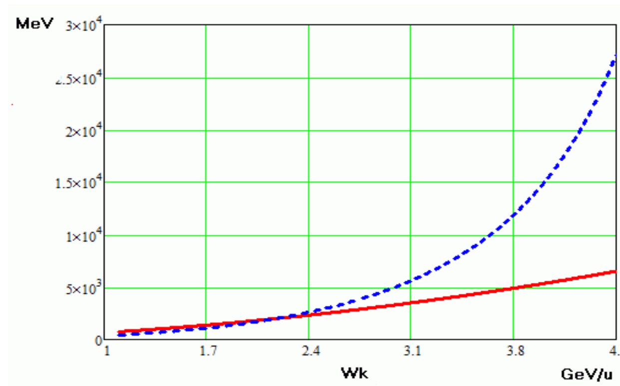

Figure 1: Bucket height (red) and energy shift between synchronous Au^{+79} and Au^{+78} (blue) vs. particle energy.

The buckets of the different charge states are moving apart in the phase plane with the energy increase. Graphically the situation is illustrated by the Fig. 2.

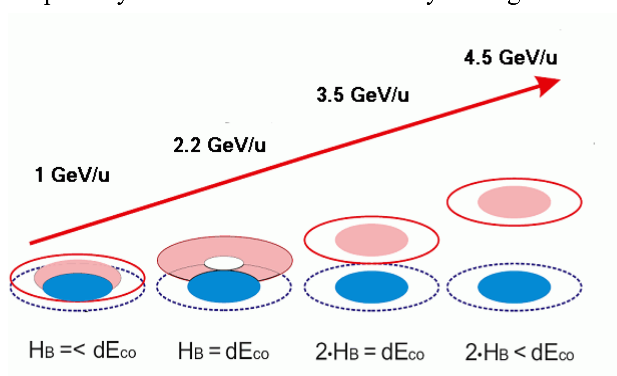

Figure 2: General scheme of buckets Au^{+79} (blue) and Au^{+79} (red) allocations in longitudinal phase space.

Thus new formed ions of Au^{+78} can find themselves either inside or outside the bucket in the energy range from 1 to 3.5 GeV/u and outside the bucket only in the range 3.5 ÷ 4.5 GeV/u. Particles inside the bucket are

ISBN 978-3-95450-125-0

involved in synchrotron motion and move in the phase plane within the envelope surrounding the new orbit. Particles outside the bucket follow flow lines parallel to the dispersion orbit.

Non-synchronous (Chaotic) Motion of Particles after their Recombination with e^-

The dispersion orbit is the trajectory of the initially synchronous Au^{+79} after its recombination with a cooling electron and turning out outside the new bucket. The radial shift of the orbit is equal to:

$$\Delta R = \frac{\Delta Z}{Z_0} D_x. \qquad (5)$$

Where D_x is the dispersion function and ΔZ is the charge variation.

Trajectories of other particles are parallel to the dispersion orbit. Their position above or below depends on their momentum at the moment of recombination. An ion will survive in collider's vacuum chamber if its trajectory doesn't exceed the radius of aperture in the place of the dispersion maximum. The vacuum chamber radius in the horizontal plane is ± 0.06 m. Figure 3 shows that coasting beam within aperture limits contains not only ions of Au^{+78} but ions of Au^{+77} as well, number of which increases with energy. Scrapers with proposed position at radius of 4 cm at maximums of dispersion are necessary for clearing out the ions Au^{+77}.

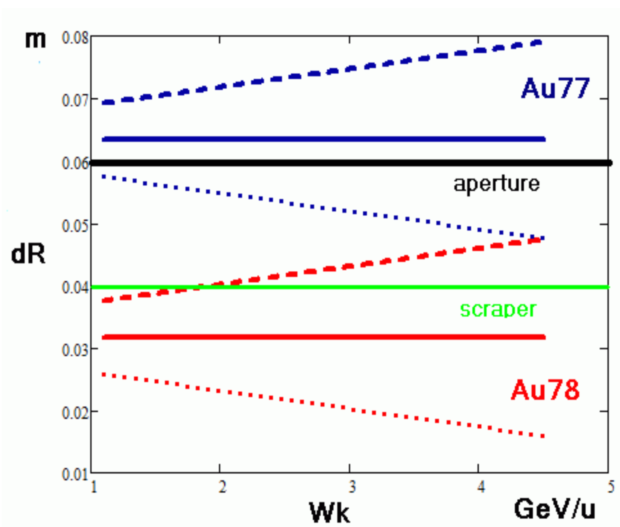

Figure 3: Coasting beam of Au^{+78} and Au^{+77}. Radial shifts of their orbits (solid lines) and envelopes (dashed and dotted lines) in maximum of dispersion.

Au^{+78} Ions Involved in Synchrotron Motion

Buckets of Au^{+78} and Au^{+79} overlap in energy range 1 ÷ 3.5 GeV. Thus newly recombined ion can found itself within its bucket and can move in the envelope near the new orbit. As opposed to the trajectories of chaotic motion the trajectories of the particles involved into synchrotron motion always cross the dispersion orbit. It means that synchronous particle will be the last one lost on aperture of scraper. The orbit displacement from the center of the vacuum chamber increases with energy growth. The position of the orbit and envelope at maximum of the dispersion value for the Collider parameters is shown in the Fig. 4.

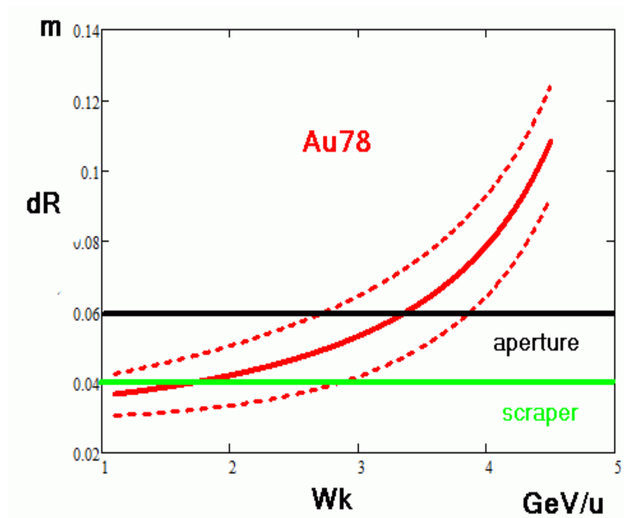

Figure 4: Particles Au^{+78} involved in synchrotron motion. Radial shift of their orbit and envelope in maximum of dispersion from the central orbit (Au^{+79})

The orbit of Au^{+78} crosses the radius of scrapers position at energy of 1.7 GeV/u. Thus the multi-turn synchrotron motion is possible below this energy only. Here the particle life-time is less than the half of the synchrotron period. At 2.8 GeV/u lower limit of the envelope crosses scraper "position". Over this energy the synchrotron motion is impossible in principal.

Upper limit of the envelope exceeds the radius of scrapers starting from the minimum collider energy. It means that ions of Au^{+78} moving in the vicinity of the separatrix will be lost on scraper at the energy above 1 GeV/u.

The simulations of Au^{+78} motion have been done using ESME code [3] at different ion energies. The result of the simulations is shown in the Fig. 5. At 1 GeV/u multi-turn synchrotron motion is possible only for particle in the inner part of the bucket. At 1.6 GeV/u the simulation shows that only small number of particle is trapped inside the bucket.

ISBN 978-3-95450-125-0

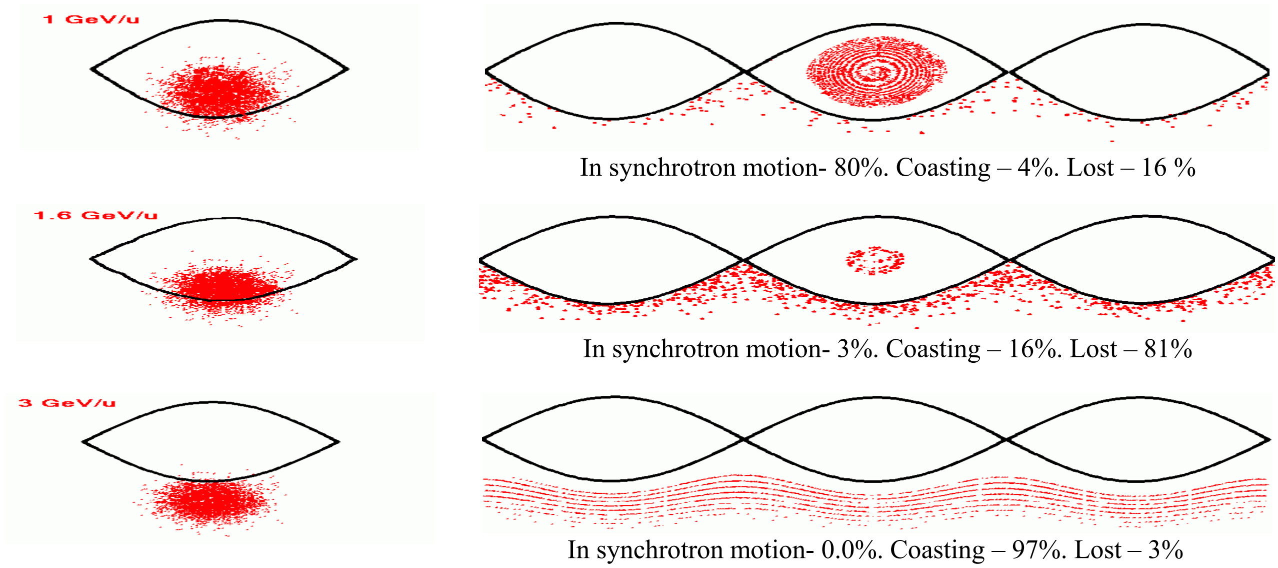

Figure 5: ESME simulation of Au^{+78} motion in longitudinal phase space at 1.0, 1.6, 3.0 GeV/u

.

INTENSITY OF THE RECOMBINED IONS

The ratio of recombined particles involved in synchrotron motion, in coasting motion and lost on scrapers depends on the energy. Scrapers eliminate all ions with charge state starting from Au^{+77}. The ratio depends on cross sections of two reactions: $Au^{+79} + e^- \rightarrow Au^{+78}$ and $Au^{+78} + e^- \rightarrow Au^{+77}$. Estimations presented in [4] show that the second cross-section exceeds the first one by about factor of 10. In this case the total proportion of Au^{+79} and Au^{+78} will have the time dependence shown in the Fig. 6.

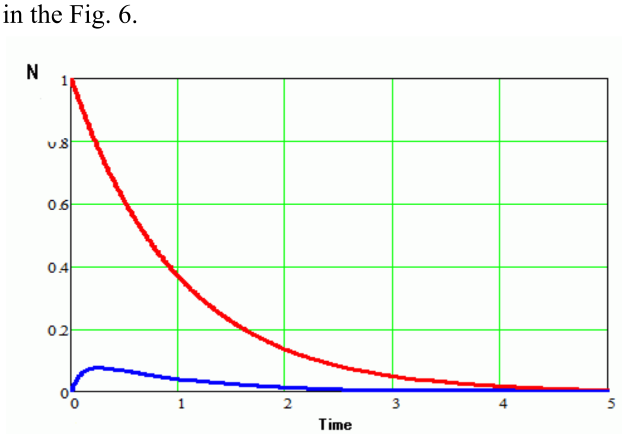

Figure 6: Change of number of ions Au^{+78} (blue) and Au^{+79} (red) in time (in number of characteristic times).

Stationary ratio of $N(Au^{+78})/N(Au^{+79})$ is inversely proportional to the ratio of the cross-sections.

CONCLUSIONS

- Ions Au^{+79}, Au^{+78}, Au^{+77} can circulate in the Collider vacuum chamber.
- Scrapers positioned at R=4 cm in maximums of dispersion function will remove Au^{+77} ions.
- Coasting ions of Au^{+78} will survive till further recombination to Au^{+77} take place.
- Part of the Au^{+78} ions involved in synchrotron motion will be cleared by scrapers. Number of ions lost by this way depends on energy.
- Ions Au^{+78} involved in synchrotron motion will be seen by the detector simultaneously with ions Au^{+79}. Ratio of their intensities can be calculated by multiplying ratio of cross sections of reaction ($Au^{+79} + e^- \rightarrow Au^{+78}$ and $Au^{+78} + e^- \rightarrow Au^{+77}$) by the portion of Au^{+78} involved in synchrotron motion.
- Number of ions Au^{+78} survived in synchrotron motion is negligible at energy above 1.6 GeV/u.

REFERENCES

[1] I. Meshkov, Status of NICA Project, these proceedings.
[2] A. Eliseev et al., "Storage, Acceleration and Short Bunched Beam Formation of 197Au79+ Ions in the NICA Collider", these proceedings.
[3] http://www-ap.fnal.gov/ESME.
[2] A. Philippov et al., "Influence of the Effect of Bare Gold Nuclei Recombination in Electron Cooling System on Working Regime of NICA Collider", these proceedings.

ISBN 978-3-95450-125-0