# 3D SIMULATION OF THE AXIAL INJECTION BEAM LINE OF DC350 CYCLOTRON

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*Abstract*

DC350 is the novel cyclotron designed in Flerov Laboratory of Nuclear Reaction of Joint Institute for Nuclear Research. It is intended for the nuclear and applied physics experiments. The axial injection channel of the DC350 cyclotron gives possibility for transportation of the high intensity ion beam from Li to Bi obtained in the superconducting ECR-ion source (SECR). The beam focusing in the beam line after the analyzing bending magnet is provided by solenoidal lenses. The linear and sinusoidal bunchers installed in the vertical part of the channel are used for increasing of the accelerating efficiency. The 3D simulation results of the focusing and bunching systems of the axial injection beam line are presented.

## INTRODUCTION

DC-350 is the new cyclotron for the Institute of Nuclear Physics of the Republic of Kazakhstan designed in the Flerov Laboratory of Nuclear Reaction of the Joint Institute for Nuclear Research. It is intended for acceleration of ions with mass-to-charge ratio A/Z within interval 4.8 □ 9.6 and energy 3÷12 MeV/u at the extraction radius. These ion beams will be used in the nuclear and applied physics experiments, in particular for synthesis of exotic nuclei. The main parameters of the DC-350 cyclotron are contained in Table 1.

Table 1: DC-350 Main Parameters

| | |
|---|---|
| Pole (extraction) radius, m | 2 (1.76) |
| Magnetic field, T | 1.24÷1.5 |
| Number of sectors | 4 |
| RF frequency, MHz | 6.45÷13.0 |
| Harmonic number | 3 |
| Energy range, MeV/u | 3 ÷ 12 |
| A/Z range | 4.8 ÷ 9.6 |
| RF voltage, kV | 80 |
| Number of Dees | 2 |
| Ion extraction method | Electrostatic deflector |

Axial injection channel of the DC-350 cyclotron [2] is shown in Fig.1. The beam line is situated above the cyclotron magnet. It consists of the superconducting ECR-ion source (**SECR**) [1] and the analyzing magnet **IM90** that is placed at the horizontal part of the channel. The focusing solenoids **IS1**, **IS2** and bunchers **IBN1**, **IBN2** are installed at the vertical part of the channel at aperture of 153 mm. The focusing solenoids **IS3** at aperture of 100 mm will be installed above the plug. The spiral inflector **I** will transfer ion beams to the median plane of the cyclotron. More detailed description of the axial injection channel is submitted in [2].

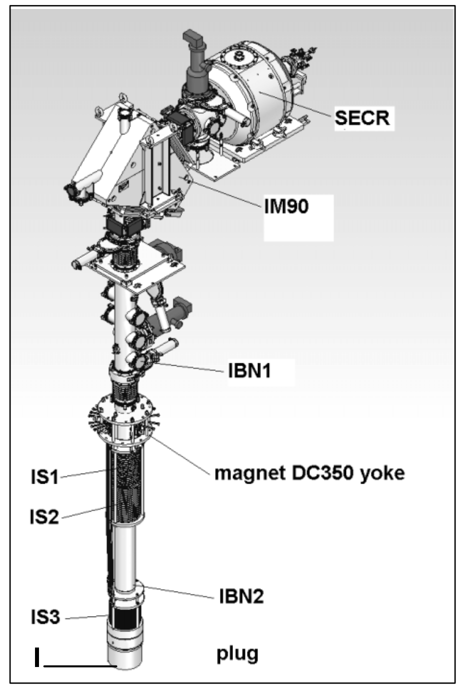


Figure 1: Beam line layout.

## ION BEAM PARAMETERS

The $^{48}Ca^{6+}$ ion beam was taken for the beam line calculations as a possible projectile for future experiments on exotic nuclei synthesis. The initial $^{48}Ca$ beam parameters used in the simulation are contained in Table 2. The charged state distributions for ion beam (Fig.2) and its self fields were taken into account in this simulation.

Table 2: $^{48}Ca$ Beam Initial Parameters

| | |
|---|---|
| Injected beam | $^{48}Ca^{6+}$ |
| Mass, A | 48 |
| Charge, Z | 2÷8 |
| Injected current, μA | 190 |
| Ca beam current, μA | 700 |
| He beam current, μA | 200 |
| $^{48}Ca^{6+}$ kinetic energy, keV/u | 3.1375 |
| Diameter, mm | 8 |
| Emittance, π mm×mrad | 142 |

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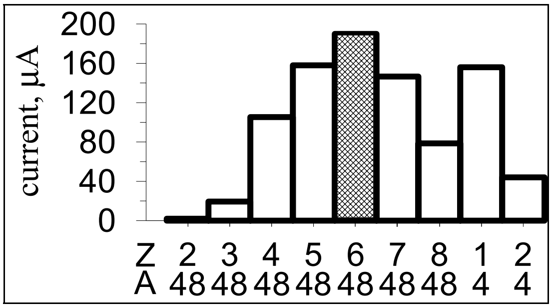


Figure 2: $^{48}Ca$ beam charge state distribution.

## MAGNETIC FIELD

The fringe magnetic field (Fig.3) of the ion source **SECR** was taken into account in the 3D simulation.

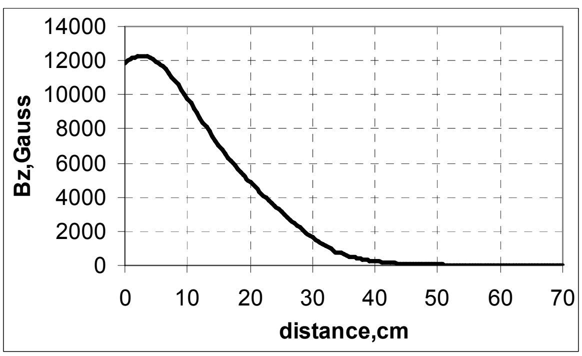


Figure 3: Distribution of the **SECR** fringe field.

The magnetic field of the analyzing magnet **IM90** was given by its map.

Distribution of the field of the DC-350 cyclotron was used in the simulation. Value of the magnetic field in center of the cyclotron was equal to 1.5 T.

The magnetic field level of the focusing solenoids **IS1**, **IS2** and **IS3** was defined via the fitting procedure to match the beam parameters with magnetic radius of the spiral inflector which is 43 mm. The magnetic fields of the focusing solenoids **IS1** and **IS2** are considered to be equal.

Distributions of the field of the DC-350 cyclotron and the focusing solenoids are presented in Fig.4.

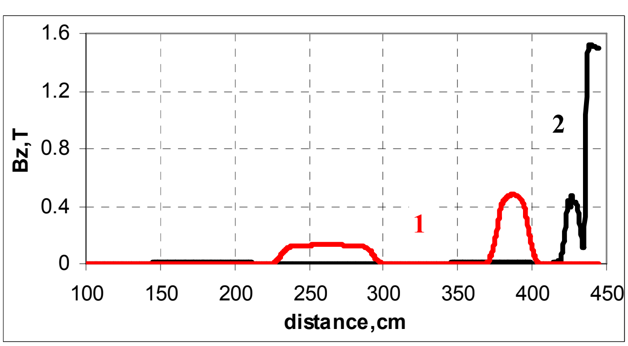


Figure 4: Distribution of the axial magnetic field (fragment): 1 – solenoids, 2 – DC350 field.

## BUNCHING SYSTEM

The bunching system consists of linear IBN1 and sinusoidal IBN2 bunchers. The linear buncher is placed at 275 cm and sinusoidal – at 80 cm from median plane of the cyclotron. Model of ideal buncher [3] was used in the simulation. The RF voltage amplitude on wire grids was equal to following values: 500 V for the linear buncher and 800 V for the sinusoidal one.

## BEAM DYNAMICS

Purpose of the simulation was matching the beam parameters with the spiral inflector. The matching condition at the entrance of the spiral inflector corresponds to the steady state of the beam (without envelopes oscillation) in the uniform magnetic field with magnitude to be equal to the field in the cyclotron center.

Following stages of the 3D simulation of the beam dynamics in the axial injection channel have been fulfilled:

1) Simulation of the beam transportation in a region filled by the fringe magnetic field of the ion source and the field of the analyzing magnet was performed by means of 2D code MCIB04 [4]. The beam reference trajectory inside the magnet has been found. Radius of curvature of the reference trajectory in the magnet central region is 38.7 cm. Corresponding value of the magnetic field is equal to 1665.15 G.

2) 3D version of MCIB04 code was used for further simulation of the beam dynamics in vertical part of the channel. It was supposed that a growth of the beam longitudinal density due to the bunching has the most significant influence on the beam exit parameters. Values of bunching coefficient along the cyclotron axis have been calculated and approximated by the tenth order polynomial that describes dependence of the beam effective current on longitudinal coordinate.

3) Fast 2D simulations of the beam transportation from the exit of the analyzing magnet IM90 to the entrance of the spiral inflector were fulfilled to fit magnetic field levels of the focusing solenoids. The beam effective current varied in accordance with the foregoing polynomial.

4) Obtained values of the magnetic fields of the solenoids have been verified by means of MCIB07 code.

The main results are shown in Fig. 5 … Fig.8.

## CONCLUSION

The 3D simulation of the $^{48}Ca^{6+}$ beam dynamics and optimization of parameters of the axial injection line are fulfilled.

It was established that optimal values of the magnetic fields of the solenoids are 1.3 kG for the solenoids **IS1**, **IS2** and 4.8 kG for the solenoid **IS3**. The beam transports with 100% efficiency. Transversal sizes of the beam are less than aperture of the spiral inflector that is equal to 6 mm. The beam slightly converges at the entrance of the inflector. Shift of the beam center-of-mass is not observed.

The comparison 2D and 3D models shows small difference in the beam emittance behavior and the bunching efficiency.

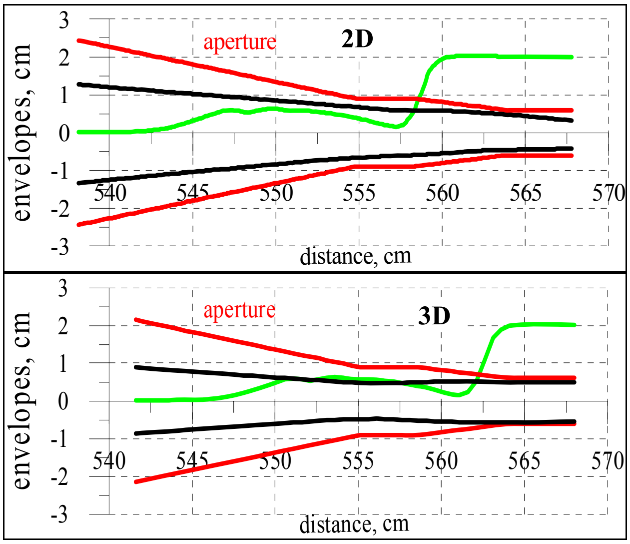


Figure 5: $^{48}Ca^{6+}$ beam envelopes near inflector. Beam current 190 μA.

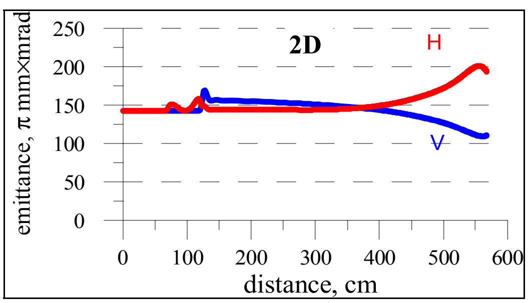


Figure 6: $^{48}Ca^{6+}$ beam emittances along the channel.

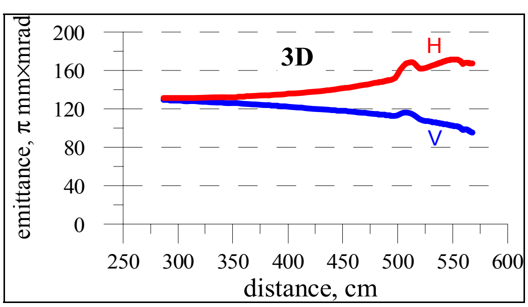


Figure 7: $^{48}Ca^{6+}$ beam emittances after the linear buncher.

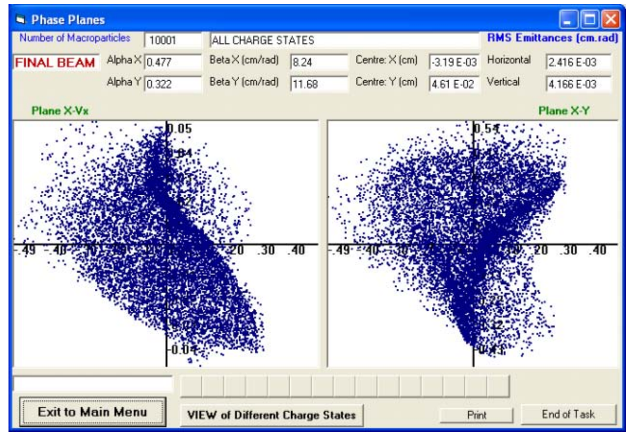


Figure 8: $^{48}Ca^{6+}$ beam face space at the entrance of the inflector (3D model).

## REFERENCES

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