CYC2016

WEA02

SIMULATION OF THE BEAM DYNAMICS IN THE AXIAL INJECTION BEAM LINE OF FLNR JINR DC280 CYCLOTRON

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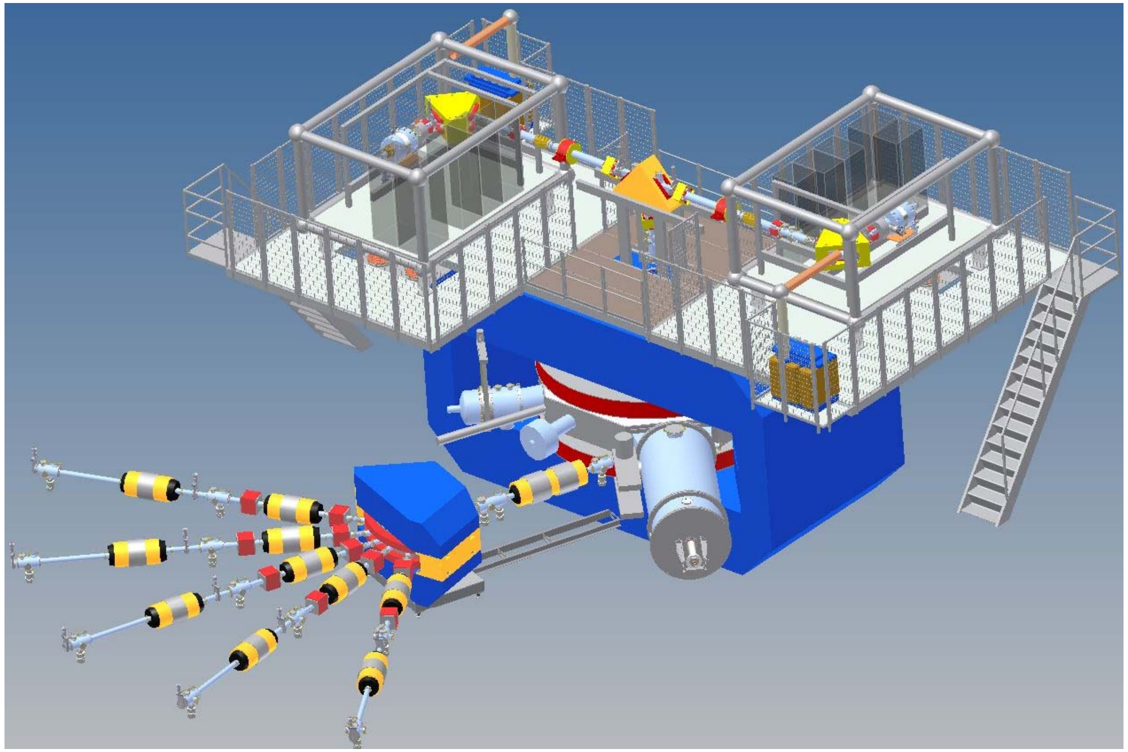
AXIAL INJECTION DC 280

DC280 is novel cyclotron which is created in the FLNR JINR. This cyclotron allows accelerating the ions of elements from Helium to Uranium with the mass to charge ratio in the range of 4 – 7.5 providing ion currents up to 10 pμA.



Layout of DC280 cyclotron

The DC280 injection system has to provide ion beam transport from the ECR-ion source to the cyclotron centre and capturing into acceleration more than 70 % of ions.

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High Voltage Platform

The efficiency of injection for ions with energies within 15 to 25 keV per unit charge is strongly dependent on the beam current. In accordance with the experience of operation of FLNR cyclotrons the efficiency of capture into acceleration is about 60% for the ion beam currents about 10 μA while for the ion currents more than 80 μA it decreases down to values less than 30%. This effect may be explained by increasing of the beam emittance at high level of the microwave power in the ECR ion source and influence of the space charge on process of bunching of the ion beam. The influence of these factors may be sufficiently reduced by increasing of the energy of injection. The axial injection system of the DC-280 cyclotron has two pieces of High Voltage Platforms (HVP). The high voltage accelerating tube is installed at the edge of the HVP to increase the ion energy (up to 100×Z keV in maximum)

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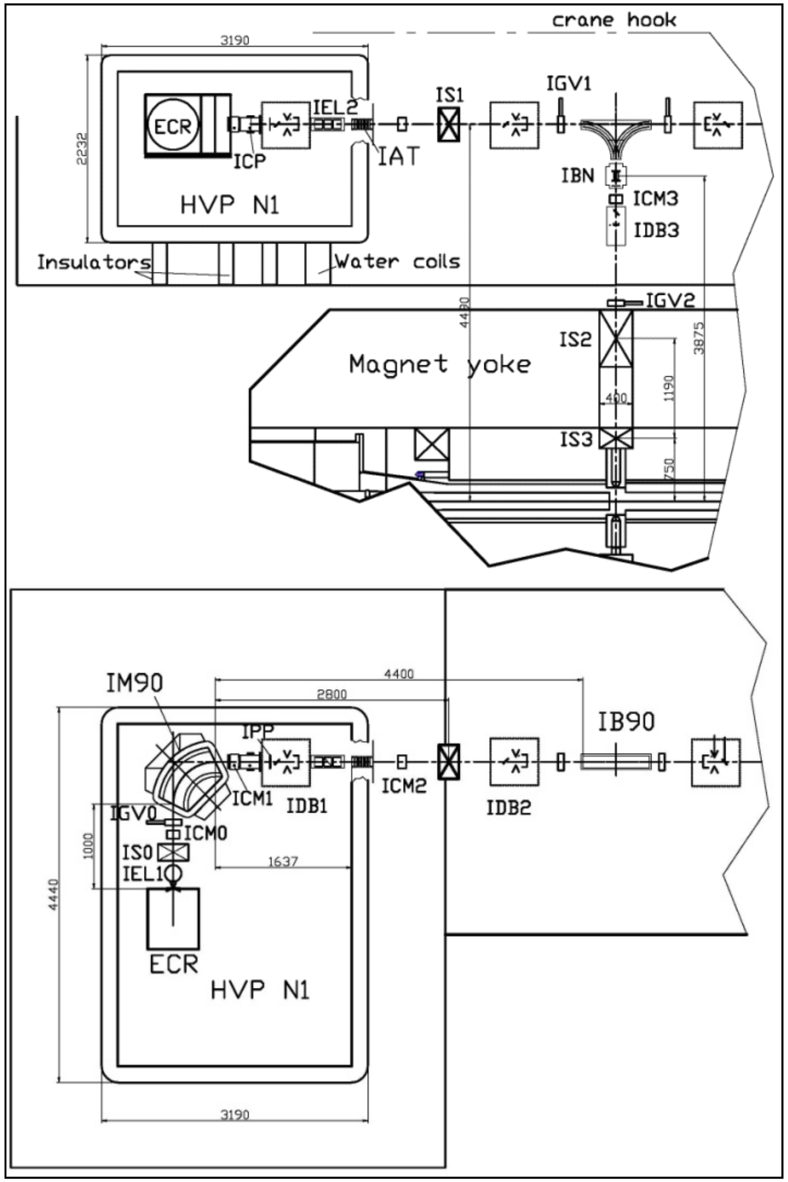
Beam Line Elements



Scheme of axial injection channel. ECR – ECR ion source; IS0-3 –solenoids; IM90 – analyzing magnet; IEL1,2 – electrostatic lenses; IAT – acceleration tube; IB90 – spherical electrostatic deflector; IBN – multi-harmonic buncher; IDB1-3 – diagnostic box.

Every HVP is equipped by an ECR ion source with injection voltage of 25 kV, the focusing element (solenoid IS0) and the magnet IM90 for ion separation. The beam is matched at the entrance of the acceleration tube by means of the electrostatic lens IEL2. For rotation of the ion beam onto vertical axis the spherical electrostatic deflector IB90 is used. To increase the efficiency of acceleration the multi-harmonic buncher IBN is applied. The ion beam emittance is matched with the acceptance of the spiral inflector by two solenoids IS2,3 installed at the vertical part of the beam line.

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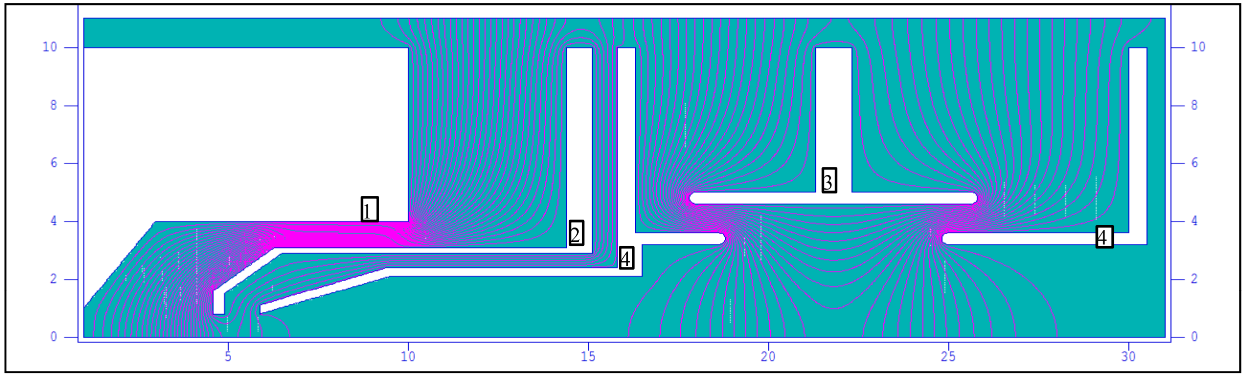
Beam Line Elements. ECR ion source

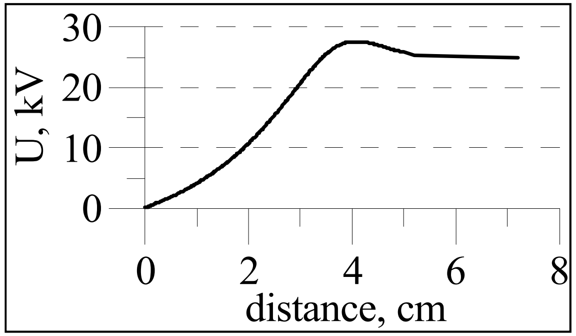
Two types of ECR ion sources are installed at HVP: the permanent magnets ion source DECRIS-PM and the superconducting ion source DECRIS-SC. The first one has to produce high intensities (15÷20 pμA) of ions with medium masses (for example, $^{48}Ca^{8+}$), the second one has to produce high charged heavy ions, such as $^{238}U^{39+,40+}$.

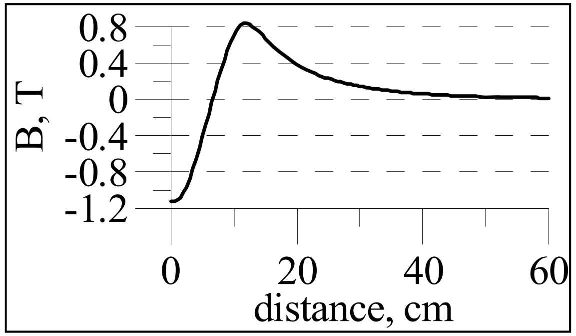
The 3D electric field map of the ECR ion source is used in the simulation



Computational model

Accelerating voltage
U_1=25 kV,
U_2=-5kV,
$U_{3,4}$=0

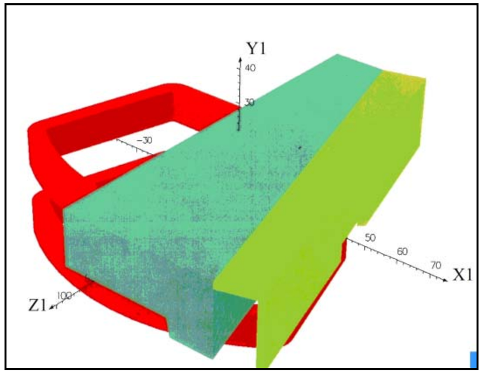




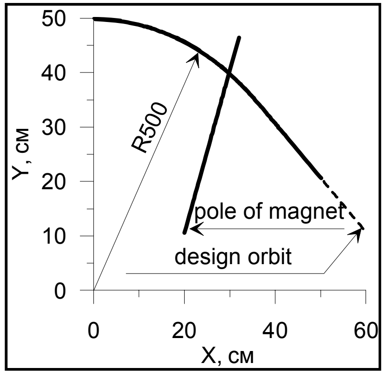
On-axis magnetic field distribution of DECRIS-PM

Beam Line Elements. IM90 magnet

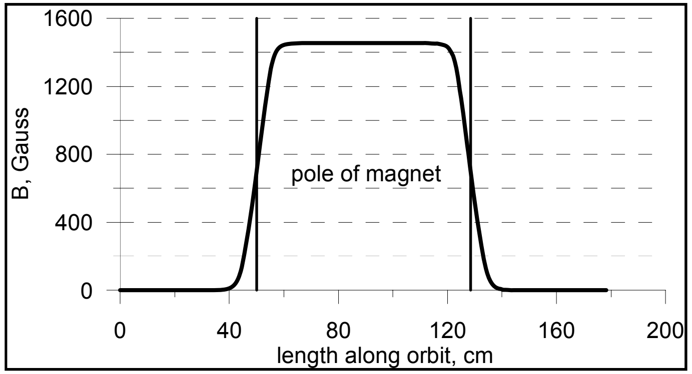
The 3D magnetic field map of IM90 magnet is used. The ion beam dynamics simulation is carried out in the curvilinear coordinate frame connected with the calculated reference orbit corresponding to the field map.



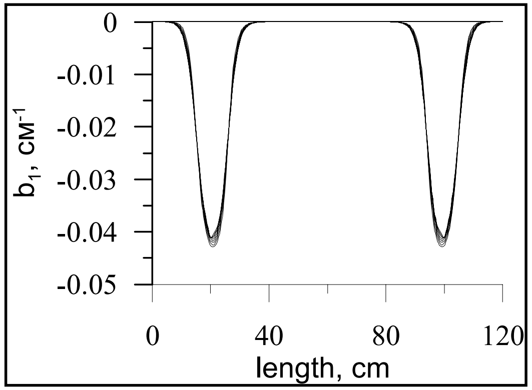
Computational model



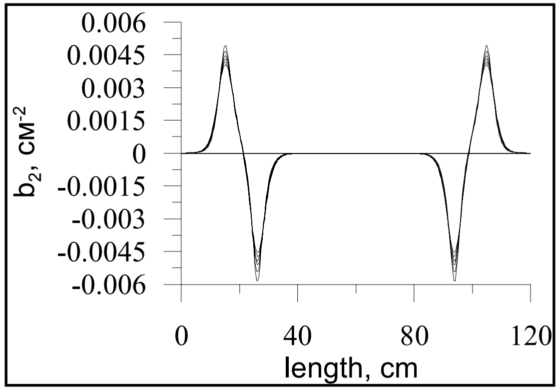
Calculated reference orbit



Bending field along reference orbit



Quadrupole component of magnetic field



Sexupole component of magnetic field

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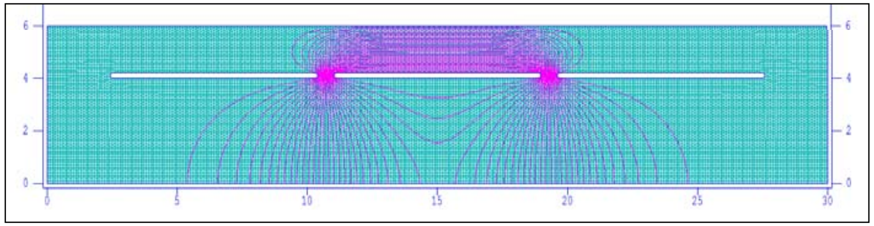
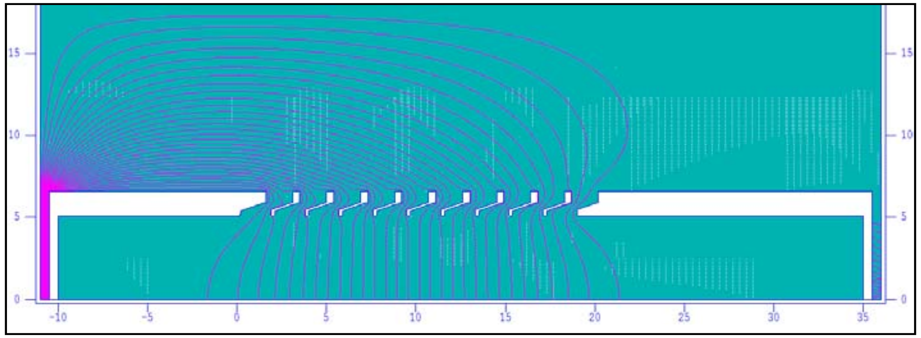
Beam Line Elements. Electrostatic Lens IEL2. Accelerating tube IAT

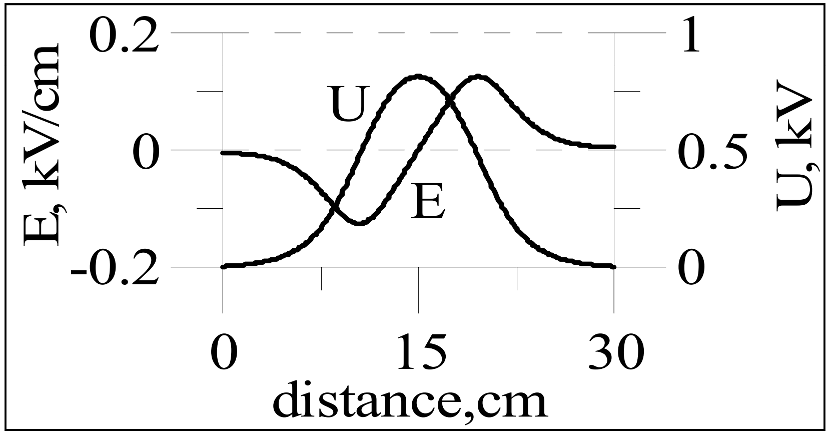
The 3D electric field map of the electrostatic lens IEL2 and the accelerating tube IAT are used.

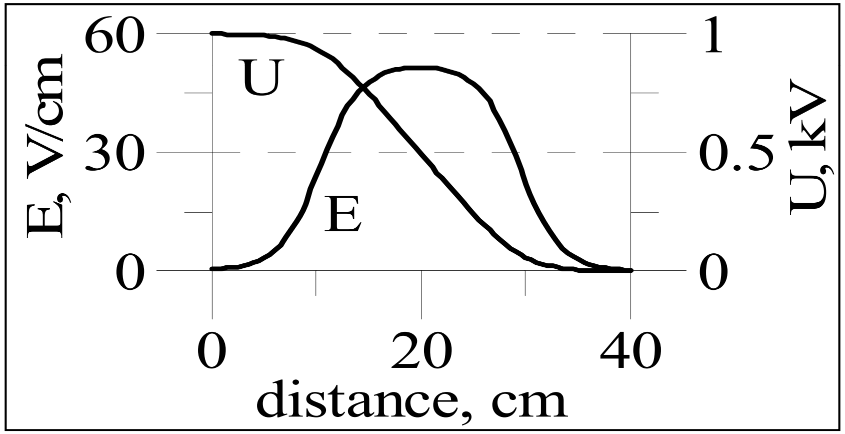


Computational model of lens IEL2



Computational model of accelerating tube IAT





The on-axis field strength E and voltage U of the lens IEL2 (left) and the acceleration tube IAT (right)

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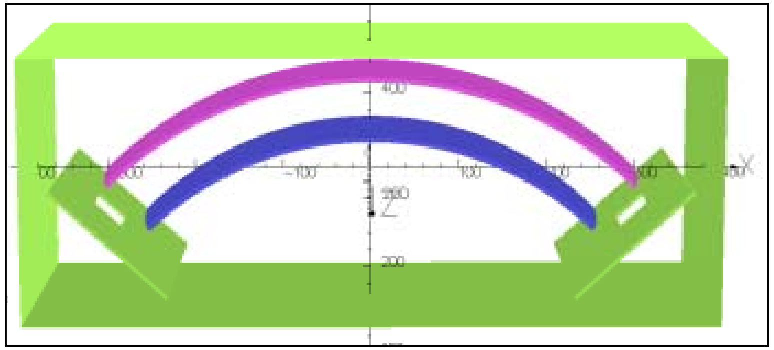
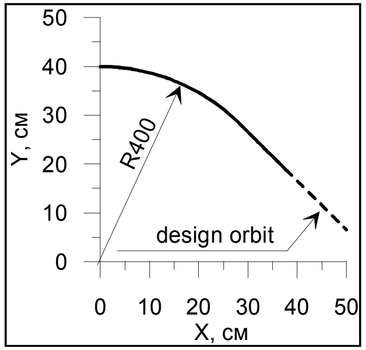
Beam Line Elements. Spherical electrostatic deflector IB90

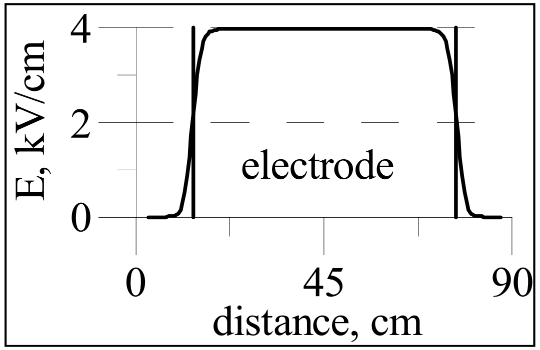
The 3D magnetic field map of IB90 deflector is used. As in the case of bending magnet the ion beam dynamics simulation is carried out in the curvilinear coordinate frame connected with the calculated reference orbit.



Computational model



Calculated reference orbit



Bending electric field

The finite width of electrodes of the spherical deflector cannot provide beam focusing the same for both transverse coordinates. This asymmetry may be minimized by shifting the equilibrium orbit towards the inner electrode of the deflector. The points of entrance and the exit at the orbit are not changed. In this regime the voltage at the inner electrode is equal to -16 kV and voltage at the outer electrode is equal to 10 kV for the maximum injection voltage Uinj = 80 kV. The deviation of the calculated equilibrium orbit from the ideal orbit at the middle of the deflector is about 8 mm.

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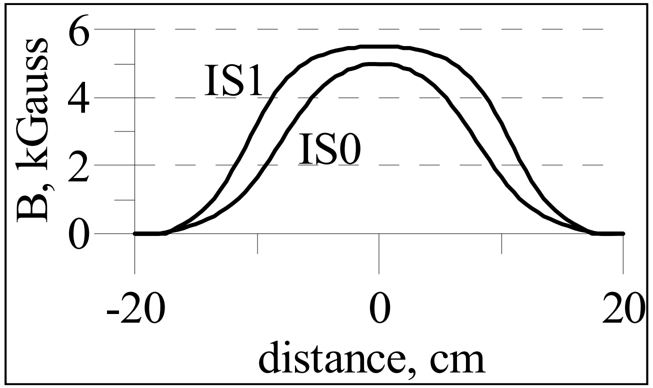
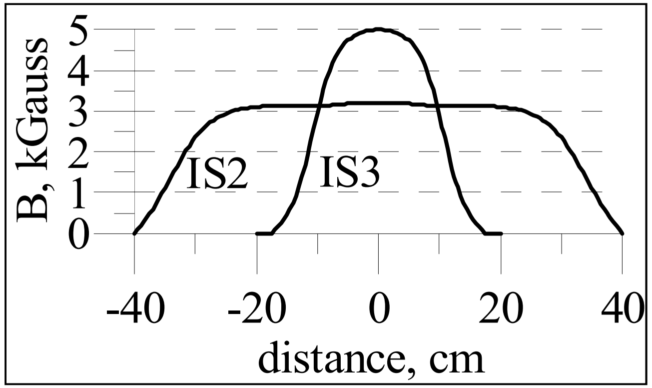
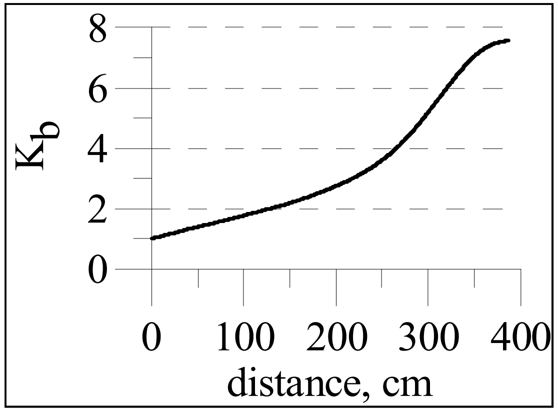
Beam Line Elements. Solenoids IS0-3

The on-axes magnetic field B of the solenoids IS0,1 (left) and IS2,3 (right)





Beam Line Elements. Multi-harmonic Buncher



In the presence of beam space charge the effect of bunching on transverse ion motion may be described by means of replacement of the beam current I by its effective value k_bI. The dependence of bunching coefficient k_b on distance from the buncher is shown here. The efficiency of the beam bunching in the 20-degrees phase interval of the accelerating RF field is equal to 80%.

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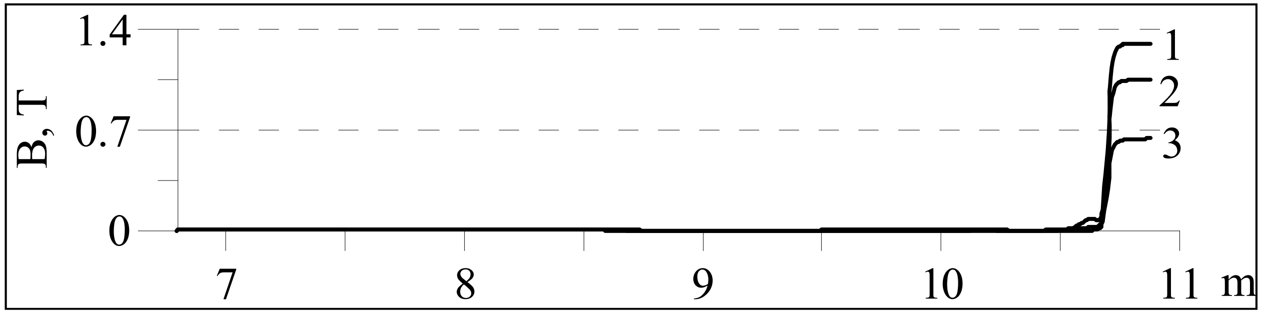
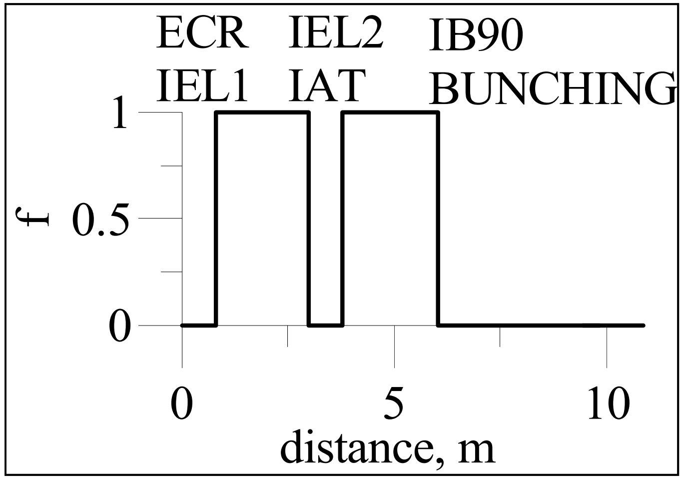
Cyclotron Magnetic Field

Three levels of the magnetic field of the cyclotron in the vertical part of the beam line B was considered in the simulation. Curve 1 – the magnetic field in the center of cyclotron B0 = 1.3 T, curve 2 – B0=1 T, curve 3 – B0=0.64 T.



Beam Neutralization



In the numerical simulations the full compensation of the beam space charge in all magnetic elements and drift spaces was supposed. The compensation was absent in the electrostatic elements and also at the vertical part of the channel after the buncher IBN. The dependence of neutralization factor f on distance along the beam line is shown here.

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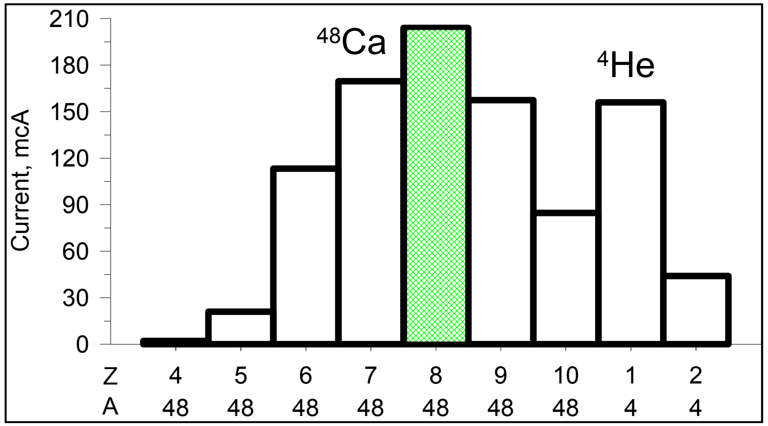
Simulation Results

The transport of $^{48}Ca^{8+}$ ion beam with kinetic energy of 75 keV×Z is presented as example. The calculated efficiency of the beam transport is equal to 100%.

Initial beam parameters

Injected ions	$^{48}Ca^{8+}$
Mass-to-charge ratio, A/Z	6
Extraction voltage, [kV]	25
Beam intensity [pmcA] / [mcA]	25 / 200
Full current, [mA]	0.952
Beam initial diameter, [mm]	8
Beam emittance at extraction energy, π [mm×mrad]	330



Beam current distribution

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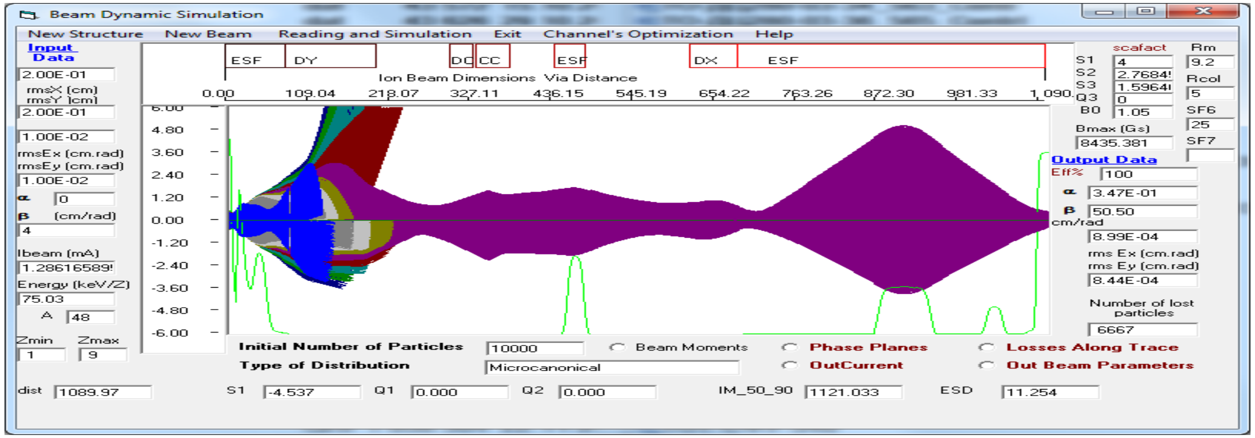
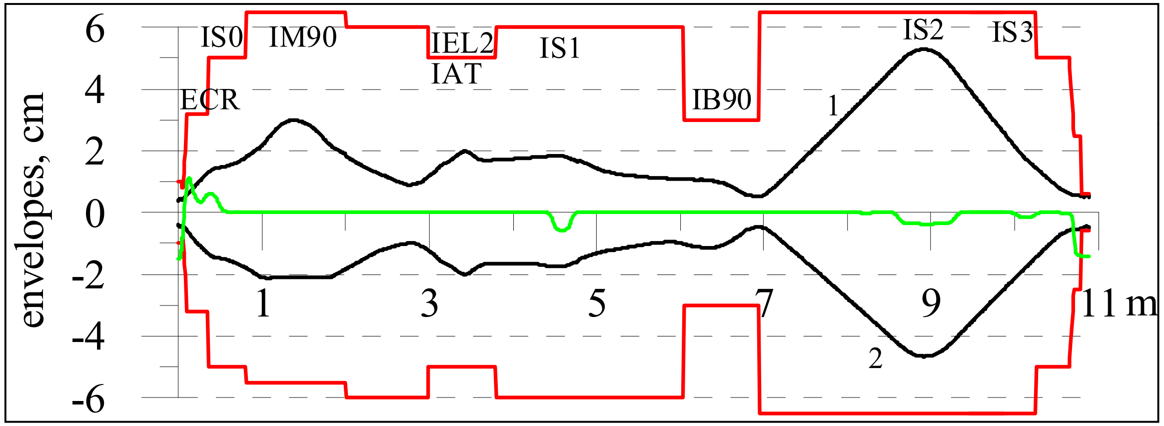
Simulation Results



User interface of MCIB04 program. Particle trajectories. Longitudinal magnetic field.



Horizontal (curve 1) and vertical (curve 2) $^{48}Ca^{8+}$ beam envelopes; aperture (red line) and longitudinal magnetic field (green line).

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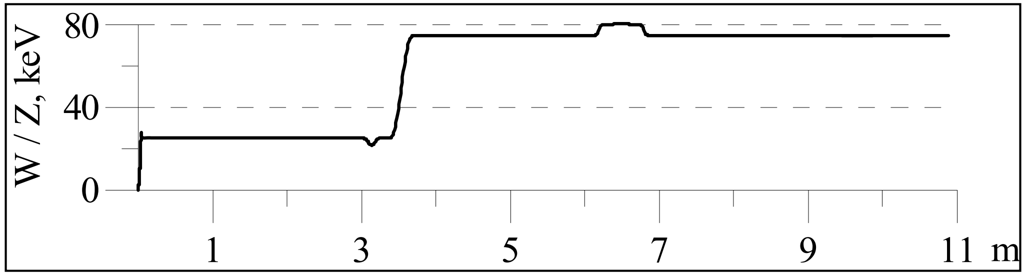
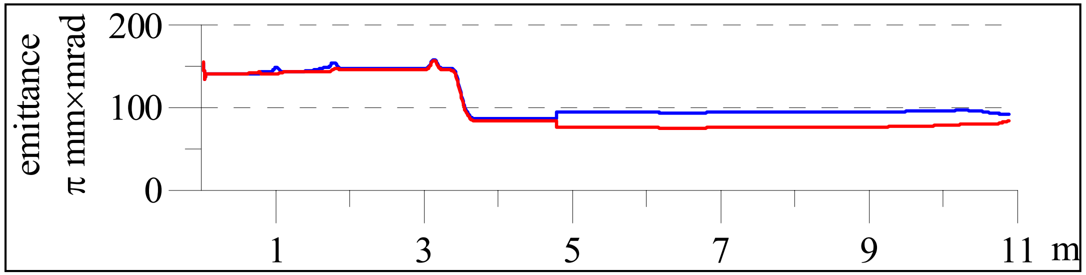
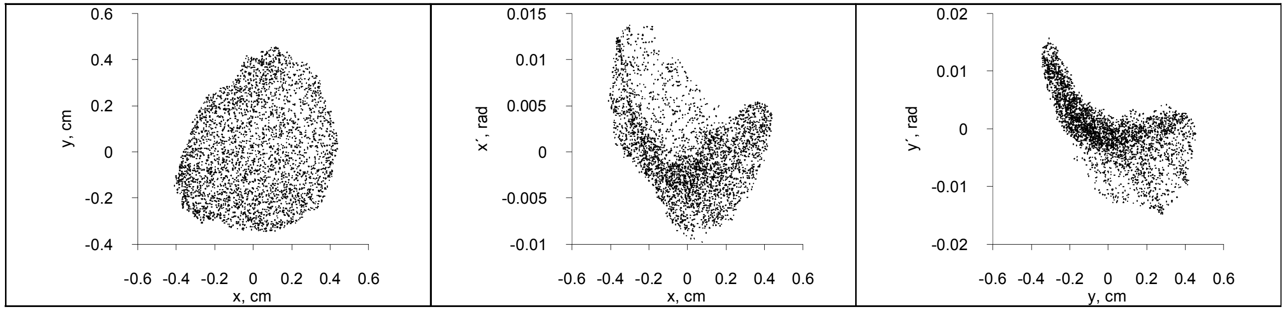
Simulation Results



Kinetic energy per unit charge



Beam emittances



Particle distributions at the inflector entrance

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SUMMARY

The simulation results show that the system of the axial injection of the cyclotron complex DC-280 is able to provide the high efficiency of capture and acceleration of the beam.

Thank you!